KFKI-71-71

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V-CENTER PRODUCTION IN POSITRON ANNIHILATION

Hungarian Academy of Sciences

CENTRAL
RESEARCH
INSTITUTE FOR
PHYSICS

BUDAPEST

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ABSTRACT

It is assumed that positron annihilation in ionic crystals is accompanied by V-center production. This leads to a definite smooth dependence of the parameters of the timelife spectra on the number of annihilations.

KIVONAT

Feltettük, hogy ionkristályokban a pozitronok annihilációját V-centrumok keletkezése kiséri. Ez ahhoz vezet, hogy az időspektrum paraméterei meghatározott módon függeni fognak a szétsugárzott pozitronok számától.

РЕЗЮМЕ

Предполагается, что аннигиляция позитронов в ионных кристаллах сопровождается образованием V-центров. Это приводит к определенной медленной зависимости параметров временного спектра аннигиляции от полного числа аннигияционных процессов.

Recent experiments suggest that the long-lifetime component in the lifetime spectra of annihilating positrons in ionic crystals is connected with A-center formation [1]. The A-center is a bound state of a positron e^+ and a positive ion vacancy V^+, and the annihilation leading to the long-lived component is ascribed to the chain

$$e^+ + V^+ \xrightarrow{\kappa} A \xrightarrow{\gamma_a} \text{annihilation}$$

The symbols κ and γ_a are the probabilities per unit time of the respective processes.

It is proposed here that the last step of this chain be specified in the following manner:

$$e^+ + V^+ \longrightarrow A \longrightarrow V + 2\gamma \qquad /1/$$

where V stands for a V-center. The reason for this is that V-centers are usually interpreted as bound states of a positive ion vacancy and an electron hole. In the present view the electron hole is produced in the process of annihilation. In the following, possible experimental consequences of this simple hypothesis will be discussed.

In [1] the interesting observation was made that only the V^+ vacancies trap positrons, V-centers remaining in this respect inactive. In chain (1) $V^+ \to V$ conversion takes place, i.e. the number of trapping centers diminishes continuously. This leads to the decrease of the trapping rate κ, which is proportional to the density of the positive vacancies. Since the lifetime of the short component τ_1 and the relative intensity I_2/I_1 of the long and short components depend on κ, they are expected to vary smoothly and in a definite manner as functions of the annihilation density rate integrated over time. If, in addition, the sample is irradiated by positrons from outside, then the density of the vacancies should become more and more inhomogeneous, so that τ_1 and I_2/I_1 become dependent on the position of the annihilation within the sample.

In order to derive the dependence of κ on time the model described in [1] will be used. The probability p(t) that a positron entering the crystal at time t=0 has not annihilated with an electron by time t is

$$p(t) = I_1 e^{-\Gamma_1 t} + I_2 e^{-\Gamma_2 t}$$

where

$$\left.\begin{aligned} I_1 &= \frac{\gamma_c - \Gamma_2}{\Gamma_1 - \Gamma_2} \\ I_2 &= \frac{\Gamma_1 - \gamma_c}{\Gamma_1 - \Gamma_2} \\ \Gamma_1 &= \gamma_c + \kappa = \frac{1}{\tau_1} \\ \Gamma_2 &= \gamma_a = \frac{1}{\tau_2} \end{aligned}\right\} \qquad /2/$$

and γ_c is the annihilation probability of the thermalized positrons.

Following [1], it is assumed that the contribution of the process $A \rightarrow V^+ + e^+$ is negligible.

The slow t-dependence of the parameters in (2) due to process (1) is determined by the equation

$$\frac{d}{dt}\left(\rho_c \cdot n_{v^+}(\underline{r},t)\right) = - \frac{\Gamma_2(\underline{r},t)\, I_2(\underline{r},t)}{\Gamma_1(\underline{r},t)\, I_1(\underline{r},t) + \Gamma_2(\underline{r},t)\, I_2(\underline{r},t)}\, N_a(\underline{r}) \qquad /3/$$

where $N_a(\underline{r})$ is the density of positrons thermalized at position $\underline{r}$ per unit time, ρ_c is the reciprocal unit cell volume, and n_{v+} is the positive vacancy concentration per unit cell. The trapping rate κ depends on n_{v+} through the relation

$$\kappa = \nu \rho_c \, n_{v+} \qquad /4/$$

where ν is the volume capture rate characterizing the individual process $e^+ + V^+ \longrightarrow A$.

Using (2) and (4), equation (3) can be written as

$$\frac{\gamma_c - \gamma_a + \kappa(\underline{r},t)}{\kappa(\underline{r},t)} \cdot \frac{d\,\kappa(\underline{r},t)}{dt} = -\nu \frac{\gamma_a}{\gamma_c} N_a \, \kappa$$

Integrating, and disregarding $\underline{r}$-dependence, one gets

$$\left(\gamma_c - \gamma_a\right) \ln \frac{\kappa(t)}{\kappa(o)} + \kappa(t) - \kappa(o) = -\nu \frac{\gamma_a}{\gamma_c} N_a . t \qquad /5/$$

(If the positron source is built into the crystal, then the sample should remain homogeneous during irradiation and equation (5) can be applied directly.)

Introducing the dimensionless quantities

$$x = \frac{\nu}{\gamma_c - \gamma_a} \cdot \frac{\gamma_a}{\gamma_c} N_a . t$$

$$y(x) = \frac{\kappa(t)}{\gamma_c - \gamma_a}$$

equation (5) can be written as

$$x = x_o - [\ln y + y]$$

where

$$x_o = \ln y(o) + y(o)$$

The function $y(x)$ is shown schematically in Fig.1. It has an exponential character only at sufficiently large values of x. Experimental determination of this function or direct observation of a growth in V-center density would be important tests of the A-center model.

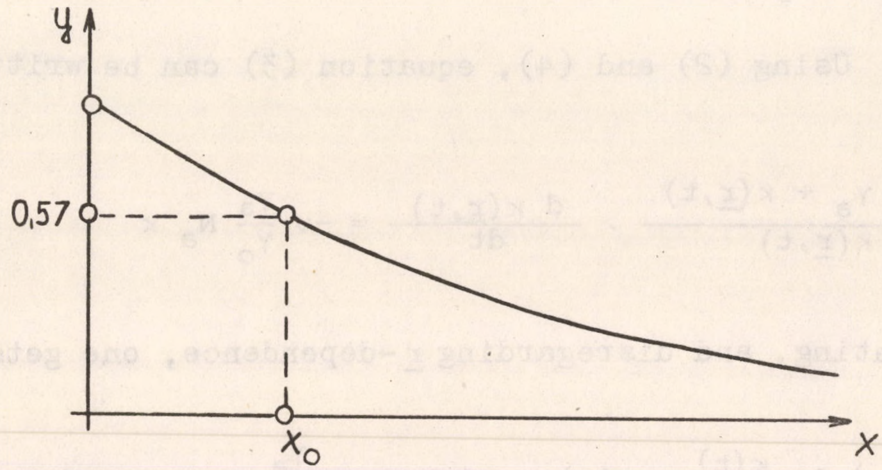

Fig. 1.

It will be noticed that the annihilation spectrum p(t) contains ν only in the combination νn_{v^+}, while in function $\kappa(t)$ the volume capture rate ν occurs in another combination. Measurement of $\kappa(t)$ in combination with the annihilation spectra might therefore lead to the separate determination of ν and n_{v^+}.

REFERENCES

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